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PREDICTING SHIP SQUAT IN NIGERIAN WATERWAYS (CASE STUDY: NIGER DELTA)

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ABSTRACT: *In view of the desire to prevent vessel grounding at port and channel entry thus, maintaining ship's continued trading, this research work presents how Maximum squats and the remaining under-keel clearances can be predictedfor two vessel categories (Container and General Cargo) along two prominent channels (BONNY ACCESS and the BONNY TO ONNE JUNCTION) in Nigeria using empirical models developed for maximum squat in the open water and confined channels conditions. The results obtained show that maximum squat increase with increasing vessel speed as the ratio of water depth to vessel draft (H/T) reduces for any particular channel or vessel. However, an opposite trend was observed with the remaining under-keel-clearances as they zero up and even cross to negatives, indicating vessel grounding; both of which agree with the results of previous researchers. Further analysis revealed that for optimal vessel safety the cruising speed within these channels should be between 0.5 knots to 5knots for the open water conditions,(H/T between1.10 -1.40),investigated. Hence, if pilots should cruise at the speed limit for the critical H/T ratio where the remaining under-keel clearance is not lower than the channel designed minimum, safety is guaranteed along either channel even with changing depths.*

KEYWORDS-*Channel, Speed, Squat, Under-Keel, Vessel*

I. Introduction

When a ship proceeds through water, she pushes water ahead of her. In order not to have a "hole" in the water as a consequence, this volume of water must return down the sides and under the bottom of the ship. The attendant streamlines of return flow are sped up under the ship with a consequential drop in pressure which in turn results in the vertical drop of the ship in water and trimming either forward or aft in the process. The overall decrease in the static under-keel clearance forward and aft is called ship squat. Essentially therefore, ship squat is made up of two components, viz; mean bodily sinkage plus a trimming effect, the excess of which will result into vessel grounding, propeller damage, rudder being sluggish, loss of business, etc.(1).

Squat is basically influenced by ship characteristics and channel geometry. Generally, the main ship parameters of importance include the speed of the vessel, the draft and the hull shape represented by the Block coefficient. Further, the proximity of the channel sides and bottom are important channel considerations. The study of squat is therefore crucial since ships of the mid-1960's and the new millennium have sizes which are even greater than their ports of destination with increased service speeds, resulting in small static even keel under-keel clearance.
Empirically, squat effect is approximately proportional to the square of the speed of the vessel. This means conversely that, the effect is reduced by a factor of four (4) when the speed is halved(1). However, squat effect is more critical when the depth/draft ratio is less than four (4) or when sailing close to a bank, entering and navigating a canal/river or narrow channel. If ship is in shallow waters and with too great speed particularly, where the static even keel under-keel clearance is 1.0 to 1.5 meters then, grounding due to excessive squat could occur at the bow or at the stern. Full-form ships such as Supertankers or OBO vessels with large Block coefficient and resultant higher squat effect will generally ground at the bow when initially stationary and on an even keel. For the same conditions, fine-form vessels such as passenger Liners or Container ships with reduced squat effect due to smaller Block coefficient will generally ground at the stern.

The problem of squat had since been investigated by so many researchers because when excessive, it results to vessel grounding whose remedial is always cost effective. Barrass in his book,(1) listed about Nine (9) ship groundings due to excessive squat between 1987 to 2003, a trend that calls for concern and so the need for renewed research in this area. It is therefore not surprising why the UK Department of Transport over the last 20years issued four "M" notices concerning the problems of ship squat and accompanying problems in shallow waters.

Interestingly, it was Constantine in 1960 among the earliest researchers on squat that made an in-road

into the physics of squat while investigating the movement of ship in restricted waterways (2). He conducted relational study on the squat behavior with respect to the subcritical, critical and super-critical vessel speeds and depth-based Froude Number. According to him, the depth-based Froude Number is less than one in the Sub-critical domain, one in the Critical domain and more than one in the Super-critical domain.

Extending the works of Constantine, Tuck in 1966(3) derived formulas for wave resistance, vertical forces and pitching moments for both the Sub-critical and Super-critical ship speeds. While deriving non-dimensional coefficients for sinkage and trim, he found out that sinkage was dominant within the sub-critical vessel speed whereas, trim dominated in the super-critical vessel speed. These when validated against results from model experiments showed satisfactory agreement.

Tuck in a counter-part work in 1967(4), also proceeded to solve a problem on the cross-section through a ship in a canal of constant depth and width using Fourier transforms. By integrating by parts the hull boundary condition and applying the assumption of zero sectional area at the bow and stern, he found out that the percentage increase in mid-ship sinkage from open water to a rectangular canal was governed by the quantity:

$$\frac{w}{L}\sqrt{1-F_h^2} \qquad [1]$$

Where, L is the ship's waterline length, F_h is the depth-based fraud number and W is the width.

(5), while studying hydrodynamic forces on ship in dredged channels extended the works of Tuck in 1966 to dredged channels with shallow-water exterior regions on either side of the deeper channel. They solved boundary value problem to predict sinkage, trim and ship resistance for subcritical ship speeds inside the channel and subcritical or supercritical speeds in the exterior regions and discovered that the exterior shallow water region can substantially affect sinkage, trim, and wave resistance for narrow channels and increased ship speeds, especially as the exterior depths increase relative to the interior channel. This work had shown satisfactory correlation with a variety of different ships.Other notable researchers who have done investigation on ship squat under varying scenarios include (6); (7); (8); (9);(10); (1);(11)etc., to mention but a few. Interestingly, all of their findings seem to have agreed with the fact that squat phenomenon is dangerous, and more so with increasing vessel speed and smaller under-keel clearance particularly in shallow waters.

Barrass in his works on ship squat (1), had developed empirical formulae for the satisfactory estimation of Maximum ship squat for vessels operating in confined channels and in open water conditions. These formulae according to him were the results of analyzing about 600 earlier results, some of which have been measured on ships and others on ship models.

In the current work therefore, these empirical formulae have been used to predict the effect of squat on two different categories of vessel (CONTAINER AND GENERAL CARGO) initially at static even-keel-under-keel-clearances and operating along two prominent channels, BONNY ACCESS channel and the BONNY TO ONNE JUNCTION channel, that play host to a beehive of maritime activities in the Onne Oil and Gas free zone in the Rivers State of Nigeria. Results from this analysis would provide useful information on squat and guide mariners safely, both old and new, as they approach and do businesses along these very busy channels for maximum economic gains.

The objectives of this study are therefore to:

- Predict at what speed in relation to the depth of water is squat phenomenon imminent along these channels
- Recommend through analysis speed ranges for safe navigation or operation at different water depths along these channels
- Ultimately assure continued business and owner's income by reducing unnecessary downtimes or ship damage due to squat
- Create overall awareness to old and new mariners of the dangers of squat along these channels particularly with respect to ever increasing ship sizes and service speed.

II. Materials and Methods

2.1 Research inputs/materials

Vessel particulars and Channel characteristics used for the investigation are shown respectively on TABLES 1 and 2 below:

Table 1: Principal particulars of the vessels under investigation (1).

NAME OF VESSEL	TYPE OF VESSEL	C_b at full load	Speed (knots)	MAX. DRAFT(m)	BEAM (m)	Depth
SALICO FRIGO (REEFER)	General Cargo ship	0.7	17	7.5	18.8	10.2
CARMEL ECOFRESH	Container ship	0.565	21	9.3	25.14	16.4

Table 2: Depth status along the Bonny/Port Harcourt channel/permissible under keel clearance (UKC) /maximum permissible width of vessel to transit the channel. (ONNE PORT, 2015).

S/N	AREA OF HARBOUR	DESIGN DEPTH(M)	CHANNEL WIDTH (M)
1.	BONNY ACCESS CHANNEL	13.5	230M
2.	BONNY TO ONNE JUNCTION	11.0	200M
3	MINIMUM STATIC UNDER KEEL CLEARANCE (0.5M)		

2.2 Method of analysis

Computational method of analysis was applied in this study utilizing Squat predicting empirical formulae as provided by Barrass (1). Microsoft Excel was used for faster computation and plotting of graphs for better pictorial presentation of results. First, analysis was made both vessels (Container and General Cargo)under consideration ALONG THE BONNY ACCESS CHANNEL for H/T ratio between 1.1-1.4(open water condition) at various speeds.A second analysis was performed for both vessels with particulars of the BONNY TO ONNE JUCTION CHANNEL under the same conditions. Investigation was done to reveal at what operating speed vessel grounding is imminent and so, recommend maximum speed limit beyond which grounding is inevitable. Further investigation was done to reveal the minimum safe cruising speed along either channel for all possible open water conditions assuming the channel depth was sloppy or undulating.

III. RESULTS PRESENTATION AND DISCUSSION

Figures 1 and 2 below show respectively plots of maximum squat against changing vessel speed from results of squat analysis conducted for both the Container and General Cargo vessels for water depth to vessel draft ratios (H/T) of 1.1 up to 1.4, indicating the open water conditions, along the Bonny Access Channel. The trend of the graphs agrees with theoretical background of the squat phenomenon. The plots for both vessels along the Bonny Access Channel reveal that as the ratio of H/T increases, the maximum squat decreases. The plots also show that for particular H/T ratio and decreasing vessel speed, the maximum squat also decreases. See TABLES 3 and 4 below for clearer understanding.

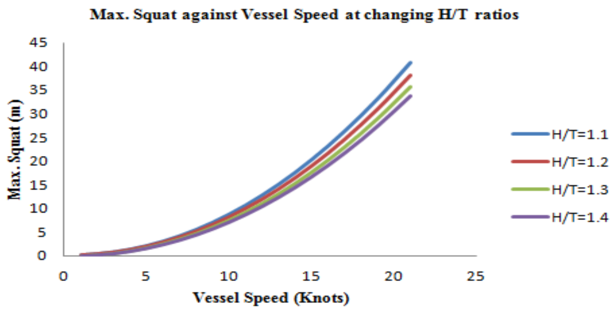

Fig.1: Squat plot for the Container vessel along the Bonny Access Channel

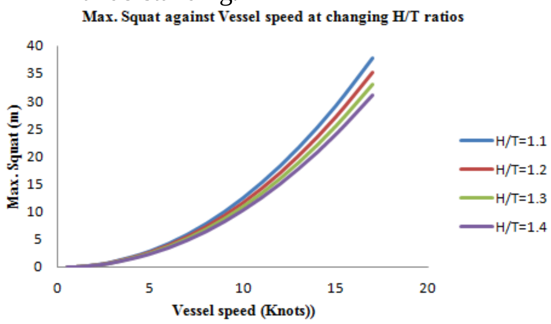

Fig.2: Squat plot for the General Cargo vessel along the Bonny Access Channel

Table 3: Max. Squat Result for the Container Vessel along the Bonny Access Channel

	H/T=1.1	H/T=1.2	H/T=1.3	H/T=1.4
V (knots)	MAX SQT (m)	MAX SQT (m)	MAX SQT(m)	MAX SQT(m)
21	40.87784648	38.09599087	35.70441879	33.62423206
19	33.19551152	30.93646101	28.99434651	27.30509748
17	26.33938508	24.54691379	23.00591926	21.66556393
15	20.3021342	18.92051528	17.73273213	16.69959967
13	15.07558064	14.0496438	13.16764191	12.40047766
11	10.65046723	9.925672149	9.302563002	8.760583361
9	7.016108474	6.538642012	6.12816224	5.771127391
7	4.159832067	3.876743471	3.633371105	3.421686092
5	2.065996038	1.925399036	1.804527247	1.699393099
3	0.713976775	0.665388592	0.623617142	0.587284381
1	0.072656065	0.06771161	0.063460843	0.05976353

Table 4 : Remaining under-keel clearances for the Container Vessel along the Bonny Access Channel

	H/T=1.1	H/T=1.2	H/T=1.3	H/T=1.4
	STERN	STERN	STERN	STERN
V(knots)	RUKC(m)	RUKC(m)	RUKC(m)	RUKC(m)
21	-39.947846	-36.235991	-32.914419	-29.904232
19	-32.265512	-29.076461	-26.204347	-23.585097
17	-25.409385	-22.686914	-20.215919	-17.945564
15	-19.372134	-17.060515	-14.942732	-12.9796
13	-14.145581	-12.189644	-10.377642	-8.6804777
11	-9.7204672	-8.0656721	-6.512563	-5.0405834
9	-6.0861085	-4.678642	-3.3381622	-2.0511274
7	-3.2298321	-2.0167435	-0.8433711	0.2983139
5	-1.135996	-0.065399	0.9854728	2.0206069
3	0.2160232	1.1946114	2.1663829	3.1327156
1	0.8573439	1.7922884	2.7265392	3.6602365

An interesting revelation is the fact that at any particular H/T ratio, the maximum vessel speed that will guarantee safe operation without excessive squat can be determined by inspection. TABLE 3 above is the squat analysis result performed on the Container ship along the Bonny Access Channel and it reveals that the safe operating speed for H/T ratio of 1.1 is 1knot. On TABLE 4, this translates to about 0.8573439m Remaining Under-keel clearance at the stern which is about71.5% above the minimum designed under-keel clearance for that Channel. Cruising at a speed of up to 3knots as TABLE 4 shows will reduce the Remaining Under-keel clearance to 0.2160232m, which is about 56.8% below the minimum value for the channel and that means danger. At 5knots within this ratio, the vessel is already sunk into the seabed at the stern by 1.135996m which should also be catastrophic to the propulsive device.

At H/T ratio of 1.2, maximum safe cruising speed is 3 knots with a Remaining Under-keel clearance at the stern of 1.1946114m. At H/T ratio of 1.3, maximum safe cruising speed is 5 knots with a Remaining Under-keel clearance at the stern of 0.9854728m. At H/T ratio of 1.4, maximum safe cruising speed is 5knots with a Remaining Under-keel clearance at the stern of 2.020607m. A little consideration should show that between H/T ratios of 1.3 and 1.4, though having the same safe cruising speed, the Remaining Under-keel clearance at the stern for H/T =1.4 has more tolerance for positive speed variation from the safe speed of 5knots.

Table5: Max. Squat Result for the General Cargo Vessel along the Bonny Access Channel

	H/T=1.1	H/T=1.2	H/T=1.3	H/T=1.4
V(Knots)	MAX SQT(m)	MAX SQT(m)	MAX SQT(m)	MAX SQT(m)
17	37.81985576	35.24610526	33.03344195	31.10886987
15	29.151166	27.16734489	25.46184618	23.9784053
13	21.64652984	20.17342092	18.90698345	17.80543755
11	15.2926552	14.25194581	13.35724391	12.57903319
9	10.07419914	9.388620766	8.799226377	8.286571794
7	5.972965894	5.5664883	5.217037933	4.913086393
5	2.966495683	2.764617077	2.591061256	2.440102595
3	1.025175743	0.95540957	0.89543132	0.843262306
2	0.441091311	0.411073772	0.385267578	0.362821378
1	0.104324452	0.097224871	0.091121334	0.085812485
0.5	0.024674236	0.022995083	0.021551509	0.020295889

Table 6: Remaining under-keel Clearances for the General Cargo Vessel along the Bonny Access Channel

	H/T=1.1	H/T=1.2	H/T=1.3	H/T=1.4
	STERN	STERN	STERN	STERN
V(knots)	RUKC(m)	RUKC(m)	RUKC(m)	RUKC(m)
17	-37.069856	-33.746105	-30.783442	-28.10887
15	-28.401166	-25.667345	-23.211846	-20.978405
13	-20.89653	-18.673421	-16.656983	-14.805438
11	-14.542655	-12.751946	-11.107244	-9.5790332
9	-9.3241991	-7.8886208	-6.5492264	-5.2865718
7	-5.2229659	-4.0664883	-2.9670379	-1.9130864
5	-2.2164957	-1.2646171	-0.3410613	0.5598974
3	-0.2751757	0.5445904	1.3545687	2.1567377
2	0.3089087	1.0889262	1.8647324	2.6371786
1	0.6456755	1.4027751	2.1588787	2.9141875
0.5	0.7253258	1.4770049	2.2284485	2.9797041

Similar inference can be drawn for squat results obtainedand as shown on TABLES 5 AND 6 abovefor the General cargo ship along the Bonny Access Channel. While both vessels have the same range of safe cruising speed, 1 to 5knots along the channel, they differ in the H/T ratio where they have common safe speed. While the General cargo ship can cruise safely at 3knots both at H/T ratios of 1.2 and 1.3 as can be observed on TABLE 6 where the remaining under-keel clearances are both higher than the channel minimum, her counterpart vessel exhibited the same trend at 5knots both at H/T ratios of 1.3 and 1.4 as TABLES 3 AND 4 showed.However, just like the former, there is more tolerance for positive speed variationat the higher H/T ratio of 1.3 where the Remaining Under-keel clearance at the stern is 1.3545687m as against 0.5445904m atH/T=1.2. This is true since at 3knots for H/T = 1.2 and 1.3, the maximum squat is higher for H/T=1.2 and so more sensitive to speed changes. See TABLE 5 above and the plots on Figs.3and 4 below. In fact, at H/T =1.3, the vessel can run at a speed of even 4knots without exceeding the minimum designed Under-keel clearance for the channel however, the vessel cannot even try 3.5knots at H/T=1.2.At H/T=1.3 and at 4knots, Remaining under-keel clearance at the stern is 0.621061m which is still higher than 0.5m minimum while it is 0.183445m; far lower than the minimum 0.5m at H/T=1.2 and 3.5knots. S

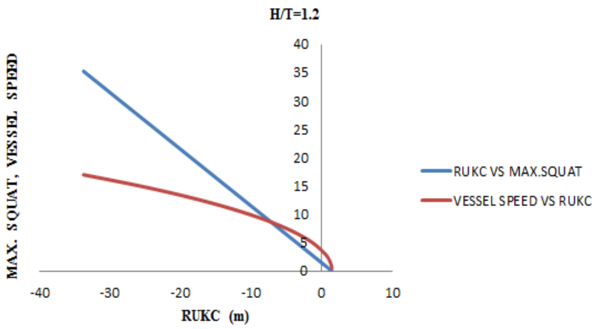

Fig. 3: Squat plot for General Cargo vessel along Bonny Access Channel for H/T =1.2

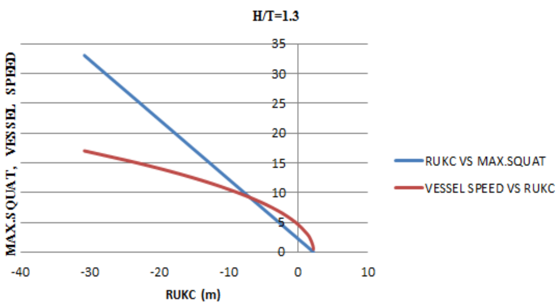

Fig. 4: Squat plot for General Cargo vessel along the Bonny Access Channel for H/T=1.3

Analysis for the Container ship along the Bonny to Onne Junction Channel reveals that only H/T ratio of 1.1 is feasible because of water depth restriction. For this case then, maximum cruising speed to guarantee safe operation is 2knots with a Remaining under-keel clearance at the stern of 0.622805m which is about 24.6% above the minimum design value for the channel. See Fig. 5 and TABLE 7 below

Table 7: Squat Result for Container Vessel along Bonny to Onne Junction Channel

		H/T=1.1
	STERN	STERN
V(Knots)	MAX SQT (m)	RUKC(m)
21	40.87784648	-39.94784648
19	33.19551152	-32.26551152
17	26.33938508	-25.40938508
15	20.3021342	-19.3721342
13	15.07558064	-14.14558064
11	10.65046723	-9.720467229
9	7.016108474	-6.086108474
7	4.159832067	-3.229832067
5	2.065996038	-1.135996038
3	0.713976775	0.216023225
2.5	0.488637837	0.441362163
2	0.307195087	0.622804913
1.5	0.168865797	0.761134203
1	0.072656065	0.857343935
0.5	0.017184207	0.912815793

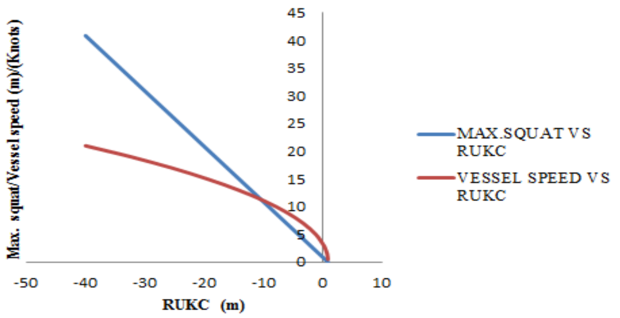

Fig. 5: Squat plot for Container vessel along the Bonny to Onne Junction Channel

Similar trend was observed for the General cargo ship along the Bonny to Onne Junction channel; see TABLE 8 below. Again safe cruising speed range is between 0.5 to 5 knots with maximum under-keel clearance at the stern of 1.354569m occurring at a speed of 3knots and H/T ratio of 1.3.

Table 8: Result of Squat analysis for General Cargo vessel along Bonny to Onne Junction Channel

	H/T=1.1	H/T=1.2	H/T=1.3	H/T=1.4	H/T=1.1	H/T=1.2	H/T=1.3	H/T=1.4
	STERN	STERN	STERN	STERN	STERN	STERN	STERN	STERN
V(Knots)	Max. SQT(m)	Max.SQT(m)	Max.SQT(m)	Max. SQT(m)	RUKC(m)	RUKC(m)	RUKC(m)	RUKC(m)
17	37.81985576	35.24610526	33.03344195	31.10886987	-37.069856	-33.746105	-30.783442	-28.10887
15	29.151166	27.16734489	25.46184618	23.9784053	-28.401166	-25.667345	-23.211846	-20.978405
13	21.64652984	20.17342092	18.90698345	17.80543755	-20.89653	-18.673421	-16.656983	-14.805438
11	15.2926552	14.25194581	13.35724391	12.57903319	-14.542655	-12.751946	-11.107244	-9.5790332
9	10.07419914	9.388620766	8.799226377	8.286571794	-9.3241991	-7.8886208	-6.5492264	-5.2865718
7	5.972965894	5.5664883	5.217037933	4.913086393	-5.2229659	-4.0664883	-2.9670379	-1.9130864
5	2.966495683	2.764617077	2.591061256	2.440102595	-2.2164957	-1.2646171	-0.3410613	0.5598974
3	1.025175743	0.95540957	0.89543132	0.843262306	-0.2751757	0.5445904	1.3545687	2.1567377
2	0.441091311	0.411073772	0.385267578	0.362821378	0.3089087	1.0889262	1.8647324	2.6371786
1.5	0.242468838	0.225968132	0.211782412	0.199443688	0.5075312	1.2740319	2.0382176	2.8005563
1	0.104324452	0.097224871	0.091121334	0.085812485	0.6456755	1.4027751	2.1588787	2.9141875
0.5	0.024674236	0.022995083	0.021551509	0.020295889	0.7253258	1.4770049	2.2284485	2.9797041

Further analysis was done to discover the effect of varying channel depth along the chosen channels. This of course is the typical scenario of the sea bottom since due to earth movements (land subsidence), wave actions on the sea bottom and surface erosion down to the channel by run-off water, sea bottom elements can sediment and settle differentially along the bottom thus, changing the water height at different points along the channel. Therefore an analysis was made assuming that for any particular channel, the sea bottom was sloping down from the highest water depth to the lowest or that or that, the sea bottom is alternately rising and sloping down (undulating) in which case all the ratios of H/T are possible along the channel. The import of this is to discover at what speed should the vessel cruise with safety irrespective of varying water depths along the channel without any risk of excessive squat leading to grounding.

TABLE 9 below presents results of analysis conducted for the General Cargo ship along the Bonny to Onne Junction channel assuming that the channel was sloping from the highest water depth to the least hence, H/T ratios change from 1.4 to 1.1 and that the vessel was cruising at the maximum speed of the channel beyond which safety is compromised and grounding imminent.

Table 9. Effect of varying water depth along Bonny to Onne junction channel for the General cargo Vessel cruising at constant safe maximum speed for the channel.

	OPEN WATER CONDITION			VARYING H/T VALUES			STERN	STERN	BOW	BOW		DYNAMIC
cb	b (m)	t (m)	B (m)	Water depth (m)	S	V (knots)	MAX SQT(m)	RUKC(m)	SQUAT(m)	UKC(m)	MBS(m)	TRIM(m)
0.7	18.8	7.5	179.22442	10.5	0.074926016	5	2.440102595	0.5598974	2.4401026	0.5598974	2.4401026	0
0.7	18.8	7.5	179.22442	10.5	0.074926016	5	2.440102595	0.5598974	2.4401026	0.5598974	2.4401026	0
0.7	18.8	7.5	179.22442	10.5	0.074926016	5	2.440102595	0.5598974	2.4401026	0.5598974	2.4401026	0
0.7	18.8	7.5	179.22442	10.5	0.074926016	5	2.440102595	0.5598974	2.4401026	0.5598974	2.4401026	0
0.7	18.8	7.5	179.22442	9.75	0.080689555	5	2.591061256	-0.3410613	2.5910613	-0.3410613	2.5910613	0
0.7	18.8	7.5	179.22442	9.75	0.080689555	5	2.591061256	-0.3410613	2.5910613	-0.3410613	2.5910613	0
0.7	18.8	7.5	179.22442	9.75	0.080689555	5	2.591061256	-0.3410613	2.5910613	-0.3410613	2.5910613	0
0.7	18.8	7.5	179.22442	9	0.087413685	5	2.764617077	-1.2646171	2.7646171	-1.2646171	2.7646171	0
0.7	18.8	7.5	179.22442	9	0.087413685	5	2.764617077	-1.2646171	2.7646171	-1.2646171	2.7646171	0
0.7	18.8	7.5	179.22442	9	0.087413685	5	2.764617077	-1.2646171	2.7646171	-1.2646171	2.7646171	0
0.7	18.8	7.5	179.22442	8.25	0.095360384	5	2.966495683	-2.2164957	2.9664957	-2.2164957	2.9664957	0
0.7	18.8	7.5	179.22442	8.25	0.095360384	5	2.966495683	-2.2164957	2.9664957	-2.2164957	2.9664957	0

As previously analyzed, the vessel was only safe from grounding at regions along the channel where the H/T ratio is less critical i.e. 1.4. Here, the water depth is highest (10.5m) and maximum squat is a minimum (2.44m). The Remaining under-keel clearance (RUKC) at the stern is also a little above the required minimum; about 12% above. However, at shallower depths representing H/T ratios, 1.3 to 1.1, the TABLE9 reveals that the vessel grounded as all the Remaining under-keel clearances were below zero (0) (negatives) as maximum squats at those regions were higher. Indeed, the same result is expected when the sea bottom is undulating. See the plot on Fig. 6 below: At water depths below 10.5m, the remaining under-keel clearances at the stern are negatives meaning that the vessel had sunk into the sea bed at the stern by the numerical values of the remaining under-keel clearances

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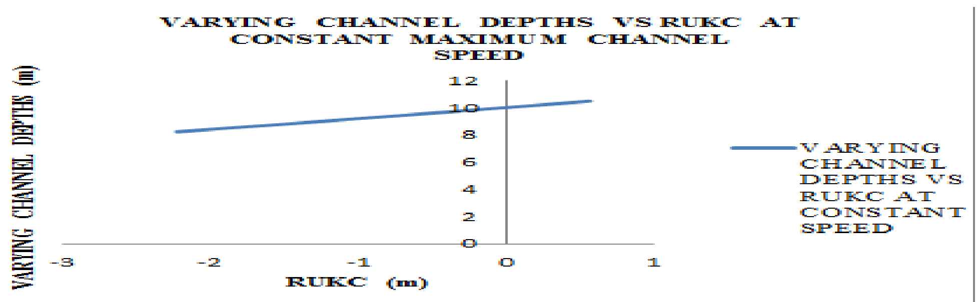

Fig.6: Plot of varying Channel depths against RUKC at constant maximum Channel speed for General cargo vessel along Bonny to Onne Junction Channel

Fig. 7: Plot of varying Channel depths against RUKC at constant minimum Channel speed for General cargo vessel along Bonny to Onne Junction Channel

When under the same condition, we ran the vessel at the minimum safe cruising speed of 1.5knots for the channel, it was discovered that irrespective of the water depth, the vessel cruised with safety all along the channel. TABLE 10and Fig.7 below show this trend where all the remaining under-keel clearances are above the designed minimum value.

Table 10. Effect of varying water depth along Bonny to Onne junction channel for the General cargo Vessel cruising at constant safe minimum speed for the channel.

	OPEN WATER CONDITION			VARYING H/T VALUES			STERN	STERN	BOW	BOW		DYNAMIC
cb	b(m)	t (m)	B	water depth(m)	S	V(knots)	MAX SQT (m)	RUKC(m)	SQUAT(m)	UKC(m)	MBS(m)	TRIM(m)
0.7	18.8	7.5	179.22442	10.5	0.074926016	1.5	0.199443688	2.8005563	0.1994437	2.8005563	0.1994437	0
0.7	18.8	7.5	179.22442	10.5	0.074926016	1.5	0.199443688	2.8005563	0.1994437	2.8005563	0.1994437	0
0.7	18.8	7.5	179.22442	10.5	0.074926016	1.5	0.199443688	2.8005563	0.1994437	2.8005563	0.1994437	0
0.7	18.8	7.5	179.22442	10.5	0.074926016	1.5	0.199443688	2.8005563	0.1994437	2.8005563	0.1994437	0
0.7	18.8	7.5	179.22442	9.75	0.080689555	1.5	0.211782412	2.0382176	0.2117824	2.0382176	0.2117824	0
0.7	18.8	7.5	179.22442	9.75	0.080689555	1.5	0.211782412	2.0382176	0.2117824	2.0382176	0.2117824	0
0.7	18.8	7.5	179.22442	9.75	0.080689555	1.5	0.211782412	2.0382176	0.2117824	2.0382176	0.2117824	0
0.7	18.8	7.5	179.22442	9	0.087413685	1.5	0.225968132	1.2740319	0.2259681	1.2740319	0.2259681	0
0.7	18.8	7.5	179.22442	9	0.087413685	1.5	0.225968132	1.2740319	0.2259681	1.2740319	0.2259681	0
0.7	18.8	7.5	179.22442	9	0.087413685	1.5	0.225968132	1.2740319	0.2259681	1.2740319	0.2259681	0
0.7	18.8	7.5	179.22442	8.25	0.095360384	1.5	0.242468838	0.5075312	0.2424688	0.5075312	0.2424688	0
0.7	18.8	7.5	179.22442	8.25	0.095360384	1.5	0.242468838	0.5075312	0.2424688	0.5075312	0.2424688	0

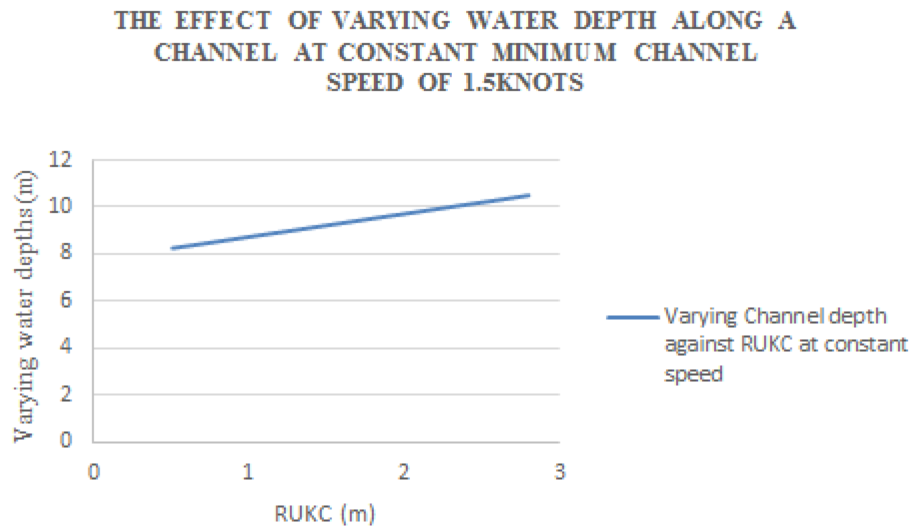

Fig. 7: Plot of varying Channel depths against RUKC at constant minimum Channel speed for General cargo vessel along Bonny to Onne Juction Channel

CONCLUSION

The authors have indeed done justice to the subject matter within the limits of the cases investigated as vessel interactive effects were not considered in this work. However, the same approach can be applied to other scenarios bordering on squat. From the forgoing analyses, speed limit ranges that could guarantee safe cruising along the channels investigated for the given vessel types and sizes have been determined accurately for the various H/T values. Results obtained have shown to be in agreement with results of other researchers as lower H/T ratio presents critical squat situation than higher H/T ratios for a particular cruising speed. Further, minimum safe cruising speed for one of the channels and vessel categories given varying water depths has also being discovered. The same trend is possible if the other cases were to be analyzed as previous analysis had shown. It is now instructive for those trading along these channels and those in the offing to be aware of squat phenomenon, the factors that stimulate it and work to prevent it in order to make the gains of their operations. High cruising Speed at channel entry or along the channel has been identified as a stimulant, particularly at shallower depths, hence vessel operators are cautioned to reduce speed at these regions in order to safely operate so as not to incur any loss due to excessive squat effect.

RECOMMENDATIONS

Squat phenomenon is an age-long subject matter and can never be easily forgotten due largely to its economic importance. It must be discussed over and over because man can sometimes be complacent with his duties. Record have it that most of the accidents occurring in the maritime industry are due largely to human errors and since humans cannot totally be taken away from industrial operations, the need to train and retrain in order to revamp

awareness is not out of place and so, to the Government, operators of ports and Ship pilots, the following recommendations are necessary.

- There should be deliberate effort aimed at constantly dredging these channels/ports in order to assure their design depths. By this, Government and operators can make full gain on their investment.
- Vessel pilots should ensure accurate sounding of the depths of these channels at entry and cruise at minimum safe operating speed along these channels to avoid incidences of vessel grounding due to excessive squat at some regions of the channel where depths may be very low.

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